Wavelet-FFNN Based Fault Location Estimation of a Transmission Line

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Abstract

In order to maintain the quality power supply and reliable operation of power delivery service to the utilities with minimum interruption, it is extremely important that the transmission line faults need to be detected and located in a reliable and accurate manner. To meet these requirement an approach based on discrete wavelet transform using neural network (NN) is proposed to estimate the fault location of the three phase transmission line and the results have been compared with the conventional method (measuring the sequence components of voltage and current). The proposed approach is based on the measurements of the three phase fault current signals at one terminal of the transmission line (at relaying point), created for different fault operating conditions using MATLAB software. To accomplish the task, features of these measured signals are extracted in terms of summation of ninth level detail coefficients using multi-resolution analysis (MRA) based on discrete wavelet transform, selecting daubechies4 (db4) as mother wavelet at 100 kHz sampling frequency. These features are then used as an input to train and test the feed forward neural network (FFNN) to provide fault location from the relaying point on the transmission line. The NN estimates the location of the fault with a significant reduction in percentage error compared to the conventional method of fault location for wide variations of operating condition. Hence, the use of multi-resolution analysis (MRA) based on discrete wavelet transform in combination with NN is quite promising for fault location estimation of the transmission line.

Keywords

Transmission Line; Fault Current Signals; Wavelet Transform; Fault Location; Feed Forward Neural network (FFNN); Ninth Level Detail Coefficients

Introduction

In power transmission line protection, faulty phase identification and location of fault are the two most important tasks which need to be addressed in a reliable and accurate manner to ensure quality performance of the power system. Since different types of transient phenomena occurs on the transmission line due to which the faulted transmission line exhibits both high frequency oscillations, localized impulses superimposed on the power frequency components and its harmonics. Therefore, from these transient phenomena, faults on transmission lines may be detected, classified, located accurately, and cleared as fast as possible. Numbers of conventional and intelligent techniques are available in the literature for the fault classification and location of the transmission systems. However, fault classification and location based on conventional methods have some limitations in achieving the desired speed, selectivity and accuracy as they do not have the ability to adapt the dynamically to the variation of operating conditions like system loading level, fault inception instance and fault resistance, etc. Therefore to overcome these problems several intelligent techniques based approaches have been implemented such as Fuzzy logic based by [Biswarup et al.(2005), Mahanty et al. (2007)], Artificial neural network (ANN) based by Samantray et al.(2007), Fuzzy neural network based by Huisheng Wang et al.(1998) , Wavelet based by [Chunju Fan et al. (2006), Osman H. et al. (2004), El safty S. et al. (2009)], and combined Wavelet-ANN techniques based by [Sami Ekici et al. (2008), Chiradeja P. et al. (2009), Nan Zhang et al. (2007), Abdollahi A. et al. (2010), Meisam et al. (2011)]. Among these approaches the Neural-network based approaches have been quite successful in identifying the type and location of fault but it requires a considerable amount of training effort for good performance, especially for a wide variation of operating conditions as mentioned above. In addition to a variation in operating conditions, the accuracy of the fault classification and location also depends on the amplitude of the dc offset and harmonics content in the transient signal of the faulted transmission line. Therefore, for detection and location of fault, it is pertinent to use waveform analysis techniques like wavelet transform which has been found to be an effective tool in monitoring and

analyzing power system disturbances including power quality assessment and system protection against faults as discussed by Samantaray S.R. et al. (2006). As a matter of fact, most of the transient signals based relay principle adopts the wavelet transform technology to construct the algorithms.

In this paper combination of discrete wavelet transform (DWT) and neural network (NN) to locate faults on the transmission line using single ended post fault (sampled fault current signals) current signals for digital relaying purposes is proposed, considering the same network as modeled by Sukumar M.Brahama (2007).The analysis produces very accurate fault location results and it is observed that the mean relative error using wavelet-FFNN based model is around 3.2 % whereas the mean relative based on conventional method (fault location measuring the sequence voltage and current) is found around 9.36 % including all cases of phase and ground faults. Hence the proposed work can be considered as an improvement over the conventional method of fault location on the transmission line.

This paper is organized as follows: First section describes the introduction, the second section represents the conventional method of fault location, the third section describe the fault location methodology using wavelet transform in combination with neural network, the section fourth and fifth describe the simulation studies, results and discussion respectively followed by conclusion and references.

Computation of Fault Location using Sequence Component of Voltage and Current

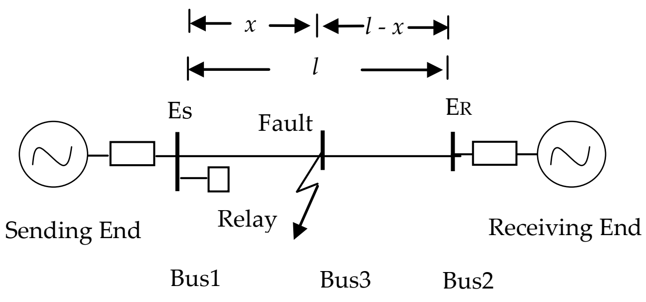

FIG.1 POWER SYSTEM MODEL

In this study a faulted transmission line extending between two power systems as shown in FIG. 1 as modeled by Sukumar M.Brahama (2007) is considered to locate the fault distance x from the sending end due to the fault occurred on the transmission line, under various fault operating conditions by measuring the sequence component of voltage and current at Bus1 and Bus3.

Computed fault locations for LG (line to ground), LLG (Double line to ground), LL (line to line) and LLL (symmetrical fault) for different fault operating conditions are depicted in TABLE 1.

Fault Location Methodology

The proposed fault location methodology scheme is illustrated in FIG. 2. At first the three phase fault current signals are obtained, considering the 100 kHz sampling rate at 50 Hz base frequency, created for different fault operating condition using MATLAB. Then Multi-resolution analysis (MRA) based on discrete wavelet transform is used to obtain the ninth level detailed coefficient of fault current signals (ia, ib and ic),selecting daubechies4 (db4) as mother wavelet as it has good performance results for power system analysis, discussed by Osman A.H. et al.(2004)]. Since in the proposed fault location scheme selected sampling frequency is 100 kHz, therefore ninth level detailed coefficients (cD9) include seconed and third harmonics which are predominant in case of transmission line faults.

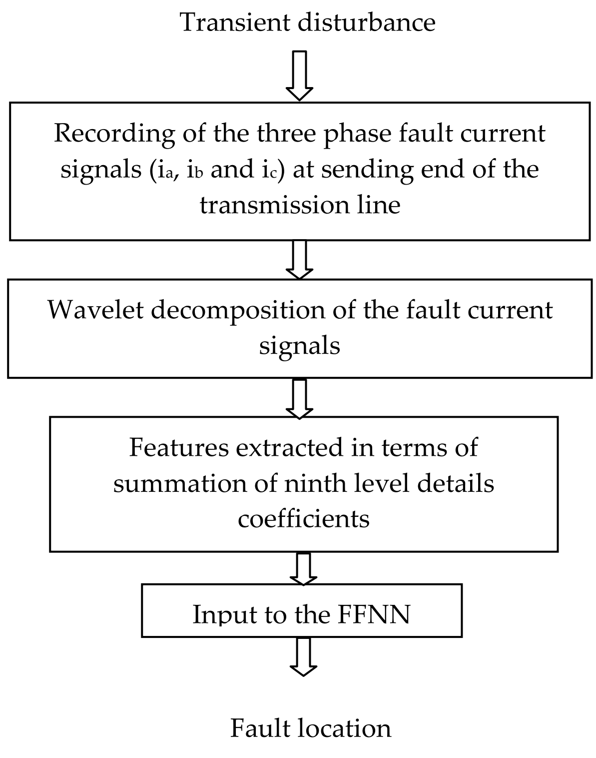

FIG.2 FAULT LOCATION SCHEME

In order to reduce the input data to the NN, in connection with accuracy and speed but retaining important feature of the wavelet signals, features have

been extracted in terms of summation of ninth level detailed coefficient for Phase A, Phase B and Phase C fault current signals summing up to N number of samples at kth instants represented by Sa, Sb and Sc. These features are then applied to the FFNN as an input and target as the location of fault distance.

TABLE 1 COMPUTED FAULT LOCATION RESULTS USING SEQUENCE COMPONENTS OF VOLTAGE AND CURRENT

Case	Types of fault	Actual distance to fault from relaying point (km)	Fault resistance (ohm)	Fault inception Angle (degree)	Receiving end phase voltage angle (δ) (degree)	Sending end zero sequence component voltage (at Bus1)	Zero sequence component voltage at fault point (at Bus3)	Sending end zero sequnence current component	Zero sequence impedance between Bus1 to Bus3 (p.u)	Computed fault location distance (x) (km)	% Error
						Magnid. (p.u)	Magnid. (p.u)	Magnid. (p.u)			
1	AG	225	1000	180	-15	2.47E-03	1.30E-02	1.25E-01	8.44E-02	210.93	6.25
2		245	1000	180	-15	2.11E-03	1.13E-02	1.03E-01	8.91E-02	222.84	9.04
3	BG	105	50	36	-15	8.08E-02	2.86E-01	4.43E+00	4.63E-02	115.77	10.26
4		240	100	90	90	2.00E-02	1.31E-01	1.04E+00	1.07E-01	266.48	11.03
5	CG	5	40	54	15	1.72E-01	1.92E-01	9.30E+00	2.22E-03	5.55	11.09
6		200	40	54	15	5.54E-02	3.18E-01	2.98E+00	8.83E-02	220.76	10.38
7	ABG	15	50	54	30	1.33E-01	1.80E-01	7.36E+00	6.51E-03	16.27	8.49
8		35	50	54	30	1.14E-01	2.09E-01	6.21E+00	1.54E-02	38.5	9.99
9	BCG	15	1000	54	-15	1.22E-02	1.67E-02	6.73E-01	6.62E-03	16.56	10.38
10		130	200	54	90	2.15E-02	8.62E-02	1.08E+00	5.99E-02	149.75	15.19
11	ACG	285	50	36	-15	2.35E-02	1.81E-01	1.29E+00	1.22E-01	304.43	6.82
12		295	50	36	-15	2.06E-02	1.64E-01	1.12E+00	1.28E-01	319.02	8.14
13	AB	65	10	54	-15	4.96E-06	1.27E-05	2.79E-04	2.77E-02	69.19	6.44
14		230	10	54	-15	3.27E-06	1.27E-05	1.14E-04	8.27E-02	206.72	10.12
15	BC	255	1	54	-15	4.03E-06	1.49E-05	9.78E-05	1.11E-01	276.48	8.42
16		280	1	36	-15	8.72E-07	7.53E-06	6.49E-05	1.03E-01	256.39	8.43
17	AC	125	10	90	-15	3.43E-06	1.47E-05	2.10E-04	5.34E-02	133.39	6.71
18		250	10	90	90	3.67E-06	9.28E-06	6.00E-05	9.35E-02	233.72	6.51
19	ABC	280	10	90	90	4.98E-16	6.30E-15	4.59E-14	1.27E-01	316.54	13.05
20		295	10	90	90	2.47E-15	5.65E-15	3.02E-14	1.06E-01	263.75	10.59

Simulation Studies

To validate the proposed fault location estimation approach, it is extensively tested on a 500 kV, 50 Hz transmission line of 300 km length connected between two sources as shown in FIG. 1 and the parameters of the system are as follows:

Sending and receiving end source voltage

Es = 500 kV; E_R = 475 $\angle\delta$ kV, where $\angle\delta$ is receiving end source phase angle;

Sending and receiving end positive and zero sequence source impedance:

$$Z_{s1} = 17.177+37.9404\,j\ \Omega;$$

$$Z_{s0} = 2.5904 + 12.2773\,j\ \Omega;$$

$$Z_{R1}=15.31+38.2704\,j\ \Omega;$$

$$Z_{R0}= 0.7229+12.6073j\ \Omega;$$

Transmission line parameters:

$$Z_1 = 0.15483 + 0.3050\,j\ \Omega/\text{km};$$

$$Z_0 =0.37432+ 0.9429\,j\ \Omega/\text{km};$$

$$C_1 =1.2097\text{E-8 F/km};\ C_0 =7.4982\text{E-9 F/km}.$$

In simulation studies, a series of test cases are created for different values of fault resistances varying from 10 to 1000 for ground faults and for phase faults 1 and 10, variation in distance in steps of every 5 km is considered from 5 km to 295 km. For simulation, a permanent fault is created at fault inception angles of 36, 54, 90 and 180 degree, which includes the zero crossing of fault signals as well, considering 0.02 sec simulation time at the sampling frequency of 100 kHz. For each fault operating condition, fault current signals at the relaying point are measured in order to be used for feature extraction using multi-resolution analysis based on DWT by equations (1), (2) and (3).

$$Sa = \sum_{k=1}^{N} CaD9\,(k) \qquad (1)$$

$$Sb = \sum_{k=1}^{N} CbD9\,(k) \quad (2)$$

$$Sc = \sum_{k=1}^{N} CcD9\,(k) \quad (3)$$

Where caD9, cbD9 and ccD9 are the ninth level wavelet details coefficients for the fault current signals of phase A, phase B and phase C respectively at the k^{th} instants and N is the total number of samples.

Results and Discussion

A large number of test cases are considered. For each fault operating condition, simulation of the program generates 59 data files that is a matrix of the order of 59x 3=177 data. Out of which 80 % of the data randomly chosen is fed to train the neural network and remaining 20 % for testing for each case. It is observed that the mean relative error for estimated fault location using wavelet-FFNN based model of location estimation is around 3.2 %. Whereas the mean relative error based on conventional method is around 9.36 %.

The error is calculated by using the following formula. The comparisons of fault location results between conventional method and by applying neural network in combination with wavelet transform for different fault operating conditions have been illustrated in TABLE 2.

$$\%\ \text{Relative Error} = \frac{|\text{Actual Location-Estimated Location}|}{\text{Actual Location}} ?\ 00$$

Conclusion

The proposed study is based on the application of wavelet transform in combination with neural network to locate the fault distance from the sending end, the analysis produces very accurate fault location results and it is observed that the mean relative error is around 3.2 % including all cases of phase and ground faults for a wide variation of fault operating conditions. The value of fault resistance has been varied from 10 Ω to 1000 Ω for line to ground fault and 1 Ω to 10 Ω for line to line fault which cover most of the high resistance faults, the variation of distance from the relay point to the end terminal in steps of every 5 km is considered, the fault inception angle especially voltage zero crossing situation has also been widely investigated in this study. Hence the application of wavelet transform in combination with NN is quite promising.

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TABLE 2 COMPARISION OF FAULT LOCATION RESULTS BETWEEN CONVENTIONAL METHOD AND APPLYING NN IN COMBINATION WITH WAVELET TRANSFORM

Case	Types of fault	Actual distance to fault from relaying point (km)	Fault resistance (in ohm)	Fault inception Angle (degree)	Receiving end phase voltage angle (δ) (degree)	Computed fault location distance (x) (km) using sequence components of votage and current	% Error	Estimated fault location using fea applied as an input to the FFNN tures vector				
								S_a	S_b	S_c	Estimated distance (km)	% Error
1	AG	225	1000	180	-15	210.93	6.25	0.0597	0.1322	0.1625	219.72	2.35
2		245	1000	180	-15	222.84	9.04	0.0587	0.1319	0.1620	239.80	2.12
3	BG	105	50	36	-15	115.77	10.26	0.5731	1.9092	0.5847	107.25	2.14
4		240	100	90	90	266.48	11.03	0.2936	0.2898	0.3735	235.03	2.07
5	CG	5	40	54	15	5.55	11.09	-0.0049	-0.0047	-0.0342	4.89	2.20
6		200	40	54	15	220.76	10.38	-0.0054	-0.0031	-0.0125	194.00	3.00
7	ABG	15	50	54	30	16.27	8.49	-0.0279	-0.0235	-0.0088	15.51	3.40
8		35	50	54	30	38.5	9.99	-0.0244	-0.0217	-0.0087	34.33	1.91
9	BCG	15	1000	54	-15	16.56	10.38	-0.0065	-0.0065	-0.0073	14.35	4.33
10		130	200	54	90	149.75	15.19	-0.0206	-0.017	-0.0176	126.42	2.75
11	ACG	285	50	36	-15	304.43	6.82	1.2801	0.5627	1.2876	281.57	1.20
12		295	50	36	-15	319.02	8.14	1.2199	0.5729	1.2550	289.87	1.74
13	AB	65	10	54	-15	69.19	6.44	2.9418	0.5175	2.5280	64.51	0.75
14		230	10	54	-15	206.72	10.12	1.5985	0.5394	1.4920	234.92	2.14
15	BC	255	1	54	-15	276.48	8.42	-0.0067	-0.0210	-0.0166	250.43	1.79
16		280	1	36	-15	256.39	8.43	0.5898	1.9720	1.5209	285.38	1.92
17	AC	125	10	90	-15	133.39	6.71	0.3981	0.0777	0.4707	127.48	1.98
18		250	10	90	90	233.72	6.51	0.3570	0.3460	0.2274	244.95	2.02
19	ABC	280	10	90	90	316.54	13.05	0.2454	0.3431	0.3114	283.12	1.11
20		295	10	90	90	263.75	10.59	0.2315	0.3292	0.2979	290.00	1.69